Thermal Analysis data exchange between ESA and NASA with STEP

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ABSTRACT

Two years ago, at ICES 97, a paper was presented describing the status of two companion open standards for electronic exchange and archival of space engineering data based on STEP (ISO-10303) technology. This two standards are: STEP-TAS: for the definition of space missions and models used in thermal analysis. STEP-NRF: discipline-independent protocol for the definition of analysis, test or operation cases/models and the bulk results produced by running such cases/models.
Associated with these standards, some high-level programs have been developed for helping with the implementation of these protocols into user applications. Now, the STEP-TAS standard has started its industrial deployment phase in Europe with the incorporation into thermal software like ESARAD and THERMICA, while the first STEP-NRF proof-of concept implementations have started with software like Dynaworks from Intespace.
In parallel, some proof-of concept studies have been performed with NASA/JPL on TRASYS and TSS software which have proven that these standards could be used for the co-operation between ESA and NASA for the thermal analysis of spacecraft. This paper presents background information on STEP and demonstrate the thermal model exchange between ESA and NASA.

INTRODUCTION

The engineering of spacecraft and other space-related equipment requires extensive computer-aided design, analysis and test work - this goes for all disciplines and certainly also for thermal control engineering. In most space projects, several organisations work together, often located at different, geographically dispersed sites and they typically use different CAx tools and computer platforms to support their engineering. In order to make the engineering process more efficient and more effective - which is best expressed in the well known faster, better, cheaper slogan - reliable, tool-independent, electronic exchange of case, model and results data is highly needed. Ideally, one would go as far as having a shared database which holds the complete electronic product definition as it develops during the product life cycle, shared between disciplines and between project partners.

The classic way of using many point-to-point converters (see Figure 1) that support the great number of tool-specific data formats does generally not deliver stable solutions. The proliferation of formats and corresponding converter tools place a great burden on software development and maintenance resources. The converter tools need to be regularly updated as data formats change or get extended on either side of an interface. The quality of the converters is often questionable and conversions often result in a considerable loss of information. Finding, implementing and maintaining a high quality mapping of concepts between two tool-specific data formats is a non-trivial task, and for a single point-to-point converter it is often very hard to justify adequate funding and development time.

test article or an operational product and where applicable their environment. The results are stored as valued properties for particular network-model components for a particular state during a run. Properties can be of scalar, vector or tensor type. Special care is taken to ensure efficient storage of sparse data structures.
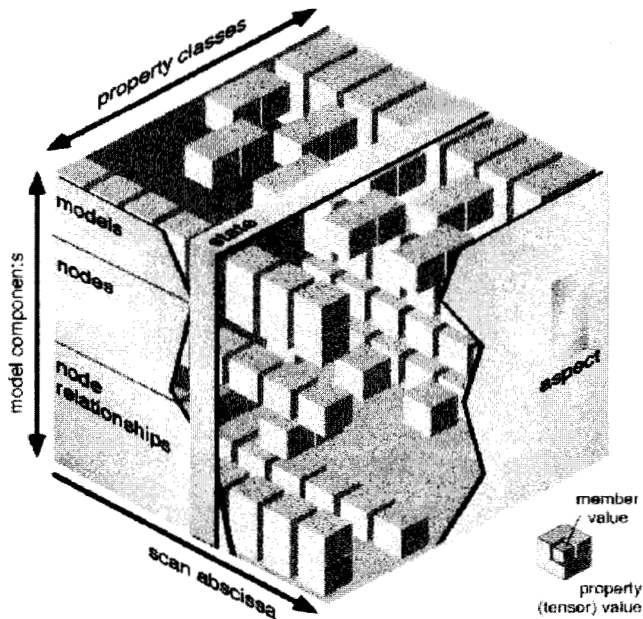

Figure 9 : The STEP-NRF values space

This protocol is developed by the STEP-TAS Consortium composed of ESA, CNES, Espri Concept, Fokker Space, Association GOSET and ALSTOM.

See : http://www.espri-concept.com/step-tas

STEP-PRP : PROPULSION SYSTEM

The domain covered by this protocol is the spacecraft propulsion system activities. In more details, the data exchanged are those involved in the simulation of propulsion systems using liquid or gas thrusters. The propulsion systems are considered as networks connecting components through connections. The data can be dimensional parameters of components, functional variables, simulation parameters or simulation results.

The objective of this protocol is to exchange simulation data between simulation tools, to exchange data between network editors and computational tools, and to exchange data between computational tools and result post processors.

For more information, contact Jean-Luc Le Gal from CNES (jean-luc.legal@cnes.fr).

STEP-MCI : MASS CENTRE AND INERTIA DATA (SUBSET OF AP214)

A document, written by Association GOSET (ref. GOSET #GDT 97 – 011), defines with reference to the ISO 10303-214 application protocol as an application

resource, the minimum subset of entities necessary to satisfy the scope and information requirements for the exchange of Mass – Centre – Inertia (MCI) data between software used in the space community.

For more information, contact Jean-Luc Le Gal from CNES (jean-luc.legal@cnes.fr).

NODIF : OPTICAL SYSTEMS DESIGN AND ANALYSIS

This part of ISO 10303 supports digital representation for computer-aided design, computer-aided engineering, and computer-integrated analysis for design and analysis of optical elements and optical systems that have their characteristics represented by parameters in optical design programs.

See: http://optics.org/oo/optical_standards/appps.html

OTHER PROTOCOLS

Some other protocols of interest (See: http://www.nist.gov/sc4/www/stepdocs.htm) :

AP 201 (IS): Explicit draughting

AP 202 (IS): Associative draughting

AP 208 (CD): Life cycle management - Change process

AP 210 (DIS): Electronic assembly, interconnect and packaging design

THE STEP METHODOLOGY

For developing a new cooperative system, STEP defines a complete methodology, which associates end-users, standard specialists and software engineers (Figure 10).
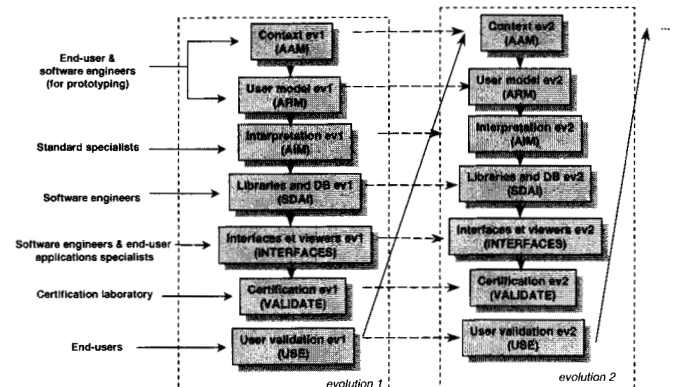

Figure 10 : The STEP methodology cycles for developing co-operation systems.

The output of the two first stages of this methodology is the Application Reference data Model (ARM) which captures the specific needs of end-users, in their own structure and terminology. This model can be defined in EXPRESS (formal language …) and can be an output of an OMT/UML case tool. This ARM is interpreted by STEP specialists who produce an Application

for the exchange between application systems of configuration-controlled 3D designs mechanical parts and assemblies.

Configuration in this context only includes data and processes that control the 3D product design data. This protocol is implemented in most CAD systems.

This protocol is an International Standard since 1994 and is a copyrighted document available from ISO or your National standards body.

AP203 is implemented in most CAD systems.

AP212 : ELECTROTECHNICAL DESIGN AND INSTALLATION

This part of ISO 10303 specifies an application protocol (AP) for design and installation information of electrotechnical equipment used in plants, industrial systems or vehicles. This part describes the information shared between the parties involved in the design, the installation and the commissioning of the apparatus. Design is understood as a process of combining components such as relays, programmable logic controllers, or software to a system. Such a system may control a chemical process in a factory. The description includes various characteristics of the design like functional aspects, physical aspects or the aspect of installing the equipment.

See: http://www.nist.gov/sc4/www/stepdocs.htm

AP209 : COMPOSITE AND METALLIC STRUCTURAL ANALYSIS AND RELATED DESIGN

This application protocol defines the context, scope, and information requirements for the exchange of the information specified necessary to perform the design through analysis stages of the life cycle of composite and metallic structural parts, and specifies the integrated resources necessary to satisfy these requirements. This includes the exchange of computer-interpretable composite and metallic structural product definition including shape, their associated finite element analysis (FEA) model and analysis results, and the material properties of these products.

This part of ISO 10303 satisfies the need for exchange of information between the iterative design and analysis stages of the product life cycle. Product configuration information provides the audit trail necessary to control the designed shape, its associated finite element model, and any related analysis shape information during these iterative stages of the product life cycle.

See: http://www.nist.gov/sc4/www/stepdocs.htm

STEP-TAS : THERMAL ANALYSIS FOR SPACE

STEP-TAS is a protocol for the definitions of space missions and models used in thermal analysis.

The space missions part comprises definitions of orbit, space thermal environment, material property environment and kinematic articulation. The model definition comprises surface geometry (including boolean constructive surface geometry), thermal-radiative properties and meshing, kinematic structure, materials and physical properties. STEP-TAS is a pure extension of STEP-NRF. It adds - or specialises - the specific constructs that are needed for space thermal analysis applications.
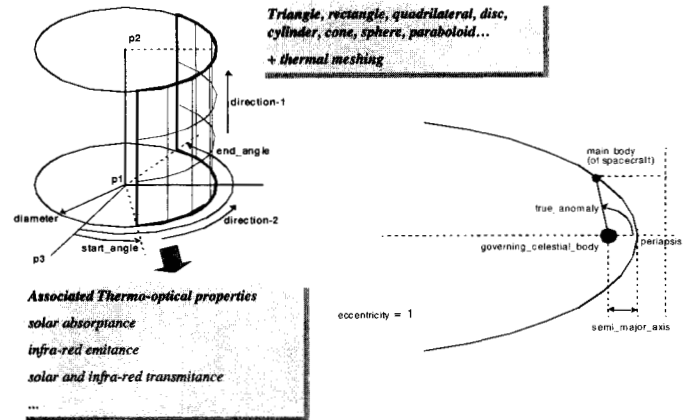

Figure 7 : Simple geometry, meshing, thermo-optical properties and orbits definitions in STEP-TAS.
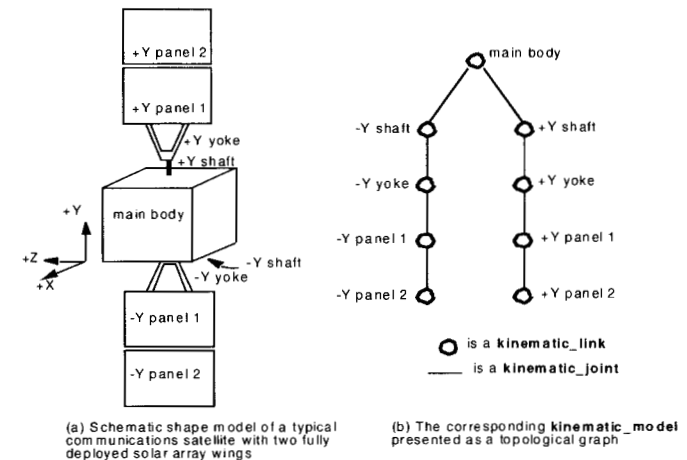

Figure 8 : Product structure and kinematics structure in STEP-TAS.

This protocol is developed by the STEP-TAS Consortium composed of ESA, CNES, Espri Concept, Fokker Space, Association GOSET and ALSTOM.

STEP-TAS is implemented in ESARAD and THERMICA.

See : http://www.espri-concept.com/step-tas

STEP-NRF : NETWORK-MODEL RESULTS FORMAT

STEP-NRF is a discipline-independent protocol for the definitions of analysis, test or operation cases/models and the bulk results produced by running such cases/models.

A generic network-model formulation is used to represent the different elements of an analysis model, a
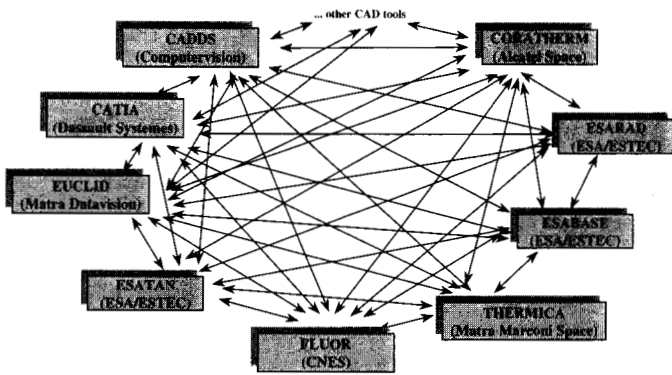
Figure 1 : Yesterday's situation in space thermal analysis data exchange.

In the European space industry, after initial implementations and prove of concept using the SET (Standard d'Echange et de Transfert – French AFNOR norm), ESA and CNES decided to use the international standard STEP (ISO-10303) (Figure 2).
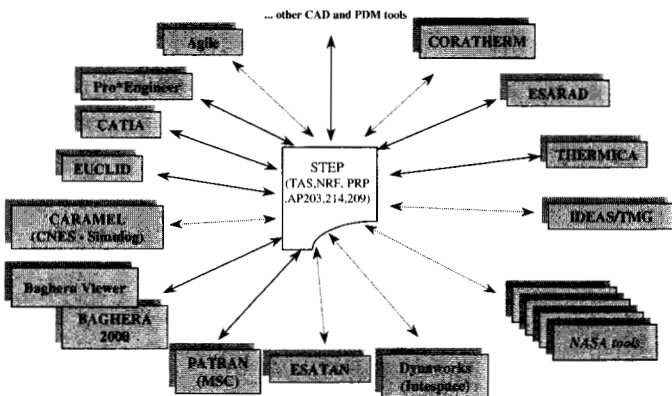

Figure 2 : In progress and future engineering technical data exchange in the European space industry using STEP.

Using STEP, all converter development efforts are concentrated on a single neutral format. It is also possible to connect to main CAD systems which now provide good STEP AP203 interfaces. So the choice of ESA and CNES was to adopt standard STEP protocols, like AP203 for CAD and AP209 for structural analysis and to develop extensions of these protocols for more space specific needs like thermal analysis (STEP-TAS), generic analysis or tests results of network based model (STEP-NRF), fluid propulsion network and others.

But what is also interesting about STEP is that this technology can be adapted for the co-operation of partners around a databases (Figure 3).
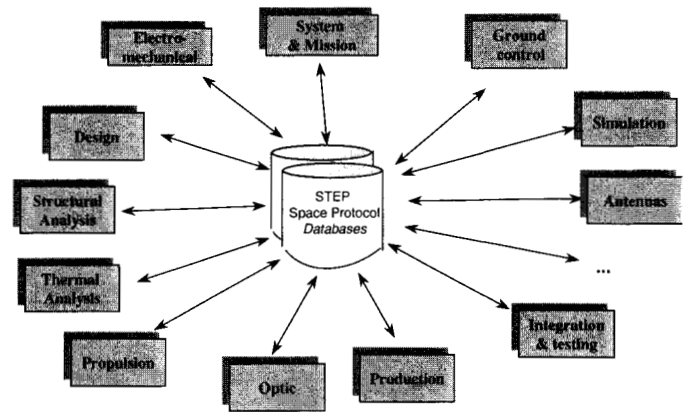

Figure 3 : Future integration of space product life cycle disciplines around STEP databases.

Actually, STEP provides , through SDAI (Standard Access Application Interface), a standard mechanism for retrieving technical data stored into an ASCII file (ISO-10303-21), into a relational or object oriented database or into a remote CORBA service.

THE STEP APPLICATION PROTOCOLS NETWORK FOR THE SPACE INDUSTRY

Among the list of ISO-10303 STEP standard or compliant protocols, some are especially suitable for the space industry. The following figure presents a possible network for these protocols :
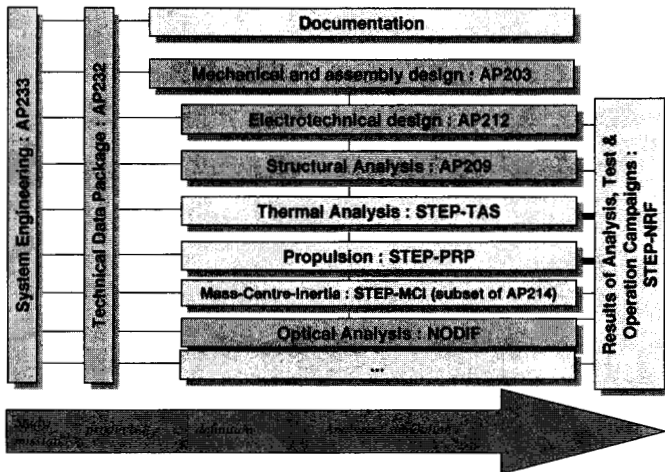

Figure 4 : The STEP Application Protocols network for space

This network presentation means that some protocols can be used for defining file formats for definition data (ex: AP203 for CAD, STEP-TAS for thermal analysis), while others can be used for defining the structure of shared databases in which some definition data could be stored as attached files (ex: AP232 for technical data package).

A short overview of these protocols follow :

AP233 : SYSTEMS ENGINEERING

According to its definition, ISO 10303 covers product definition data for the whole product life cycle. Since a product often belongs to a wider system, the role of the product inside the whole system has to be clearly defined. Their definition is the purpose of the System Engineering Design activity.

The scope of this proposal is to introduce in the ISO 10303 standard, the System Engineering data representation used during the System Design phase.

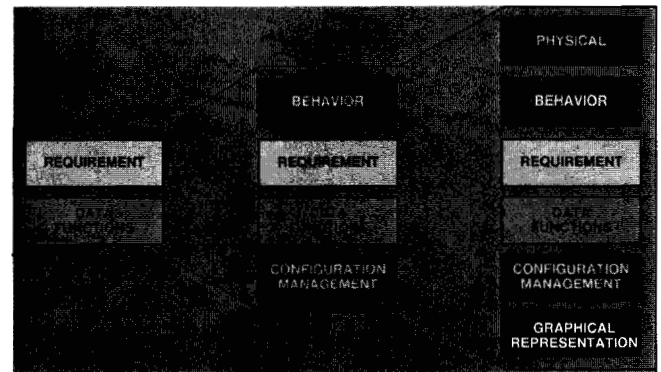This New Work Item aims at defining of a System Engineering Application Protocol.

Figure 5 : Schematic view of progressive scope of AP233

See: http://www.nist.gov/sc4/www/stepdocs.htm and http://www.ida.liu.se/projects/sedres/

AP232 : TECHNICAL DATA PACKAGE

This application protocol defines the structure to package/relate groups of product information so that configuration controlled exchanges can be achieved among Product Data Management (PDM) Systems. The emphasis will be on the information that is typically utilized for representing design disclosure of an item. The goal of this application protocol is to provide an information structure where product information can be electronically captured and managed from both a document based perspective and a product item perspective.
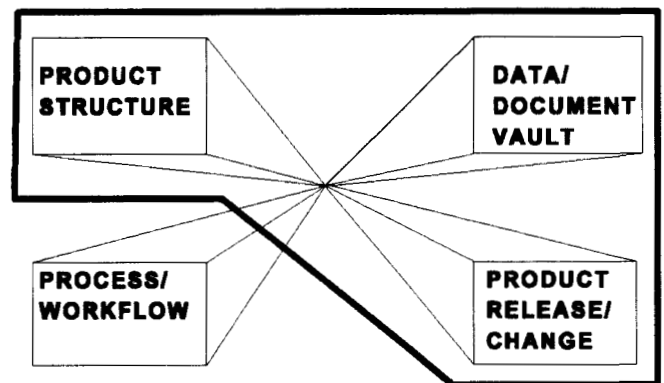

Figure 6 : Schematic view of AP232 scope

See: http://www.nist.gov/sc4/www/stepdocs.htm

DOCUMENTATION

No specific STEP protocols are defined today for space design information documentation, identification and format. As long as a need has not been clearly defined, PDF appears to be a useful standard.

AP203 : CONFIGURATION CONTROLLED DESIGN

This part of ISO 10303 specifies the integrated resources for the scope and information requirements

Interpreted Model (AIM), which is the standard point of view of the ARM, built by importation of existing integrated resources (ISO-10303-41 ... 199) and by definition of new resources connected to the existing ones.

So, at the end of this AIM stage, two EXPRESS data models are defined. These models can be loaded into a STEP toolkit (Figure 11).
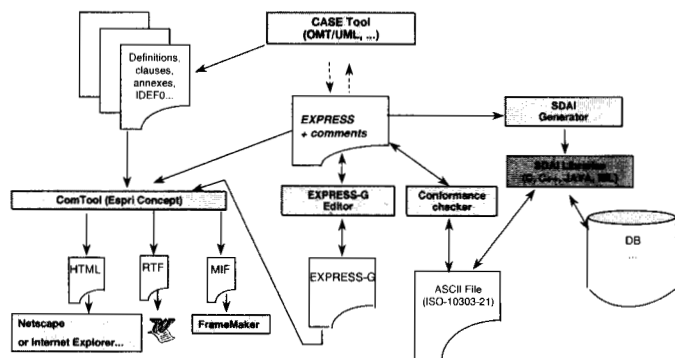

Figure 11 : STEP Toolkits, a set of tools available with the STEP methodology.

STEP toolkits provide software for building the documentation associated with STEP protocols with graphical representation in EXPRESS-G formalism and associated texts in various formats (HTML, RTF/Word, MIF/Framemaker...).

They also provide SDAI library generators. This means that using these libraries, which are set up by the loading of an EXPRESS model, it is possible to read and write the STEP instances with a programming language (C, C+, JAVA), without programming the low level source code for accessing the STEP physical format.

In addition, STEP toolkits provide tools for checking the conformance of an EXPRESS file and also the conformance of a set of STEP instances stored into a STEP physical file toward their initial EXPRESS schema.

HIGH LEVEL LIBRARIES

However, while standard STEP toolkits provide some mechanism for reading and writing STEP instances, development of standard STEP converters remains difficult for end-user application software specialists, not familiarised with STEP integrated resources.

That is why ESPRI CONCEPT has developed the concept of STEP High Level programming libraries (Figure 12).
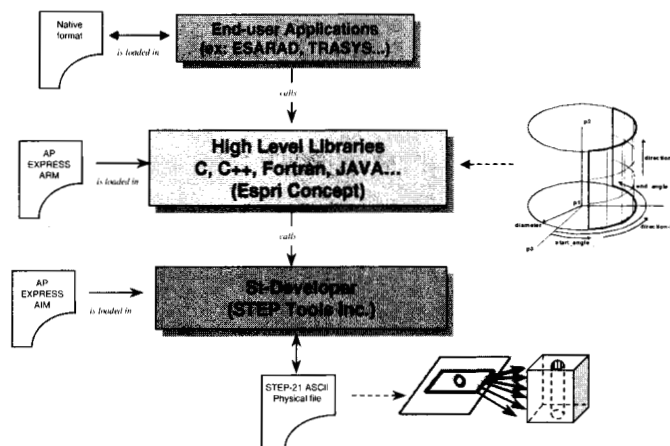

Figure 12 : High level libraries

With these libraries, end-user application software developers access the STEP standard instances via a high level API. Entry points of this API correspond to the ARM objects. So these entry points are easy to understand for end-user applications specialists because they correspond to the objects they have defined themselves.

Then, the high level libraries can be distributed for the connection of applications to the co-operation system (Figure 13).

For the development of these libraries, which is part of the SDAI stage of the methodology, ESPRI CONCEPT is associated with STEP Tools Inc. which provides the low-level SDAI toolkit for reading and writing standard STEP instances corresponding to the AIM model. High level libraries source code includes the mapping between ARM and AIM and can be developed using the EXPRESS-X language.
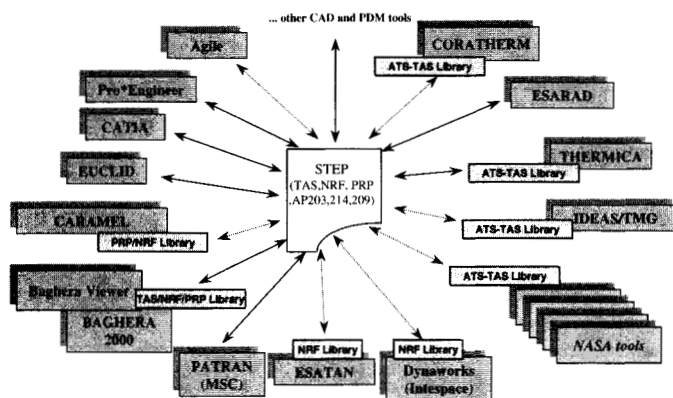

Figure 13 : Distribution of STEP-TAS High Level libraries to ESA and CNES partners for thermal analysis data exchange.

With this concept of libraries, all converters share the same source code for accessing STEP data. This result in very good reliability the exchange and a gain of time and costs in converter development.

BAGHERA VIEW FOR VISUALISING STEP SPACE PROTOCOLS

In order to further improve the reliability of STEP converters, ESPRI CONCEPT and its partners, CNES, STEP Tools Inc. and TGS, develop the Baghera View software, which permits to display the STEP geometry and associated properties (Figure 14).
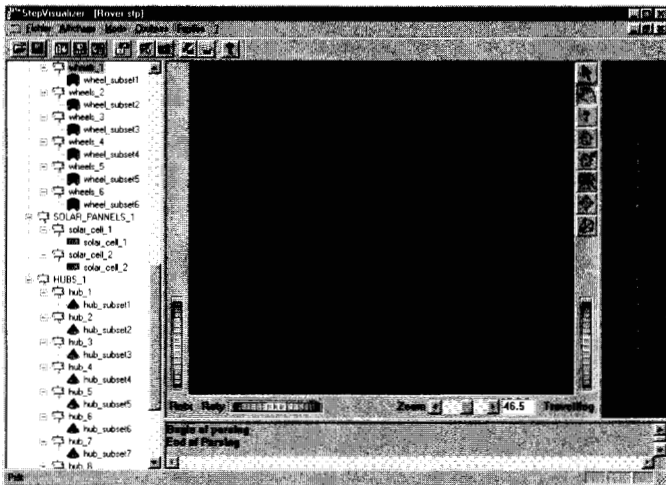

Figure 14 : After being exported into STEP-TAS, from TSS, the Mars Pathfinder thermal model is checked with Baghera View.

These viewers can be used at the converter development stage for checking geometry and the associated property transfers, and after development for displaying engineering data stored into a data warehouse in STEP format.

THE ESA/NASA THERMAL MODEL DATA EXCHANGE PROTOTYPE USING STEP-TAS

In order to emphasize the value of using the STEP technology for the exchange of thermal models, NASA/JPL decided last year to develop a STEP-TAS converter prototype for TRASYS. The final objective of this prototype was to prove the feasibility of using STEP for the model exchange between European engineers using thermal software like ESARAD, which already interfaces to STEP, and the American program TRASYS. In conjunction with this activity, the feasibility of a converter for the American TSS software was also demonstrated.

The proof-of concept study also included Baghera View for STEP-TAS files checking (see Figure 15).
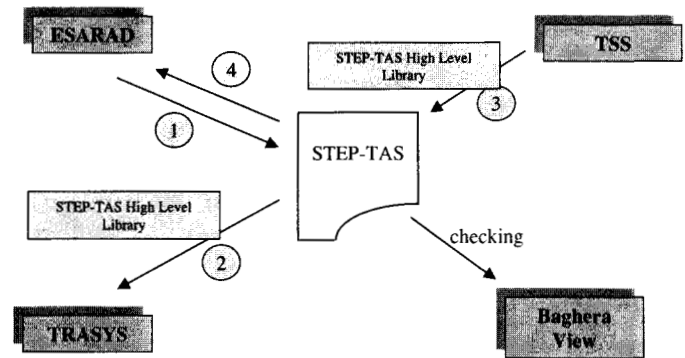

Figure 15 : The ESA / NASA prototype map

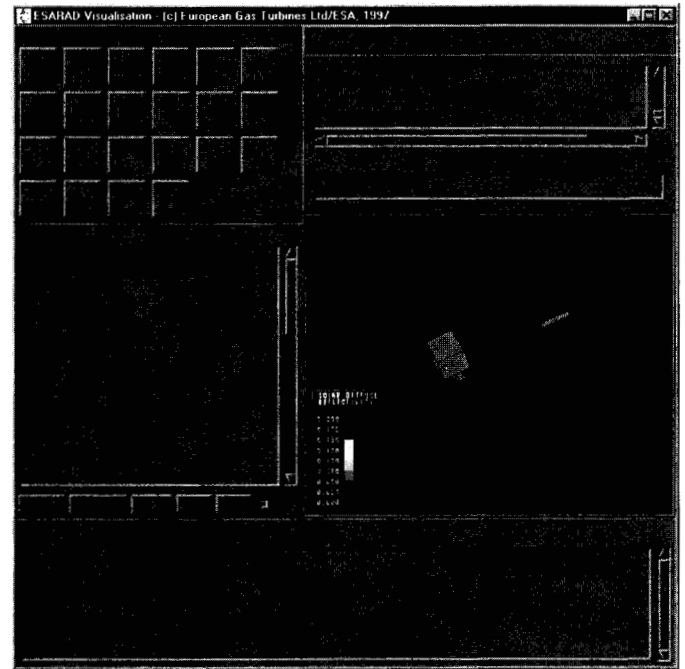The demonstration starts from ESARAD with a Rosetta model.

Figure 16 : ESARAD Input

The Rosetta model is then exported into a STEP-TAS file :

```
ISO-10303-21;
HEADER
FILE_DESCRIPTION( (''), '2;1');
FILE_NAME('ROSETTA',              '1998-04-
09T14:15:42+02:00',(''),          (''),'ST-
DEVELOPER v1.5','','');
FILE_SCHEMA (('TAS_SCHEMA'));
ENDSEC;
DATA;
...
#1400 = REPRESENTATION($,(#1190),$);
#1410 = TAS_MATERIAL_PROPERTY($,#1430,$);
#1420                                     =
MATERIAL_DESIGNATION_CHARACTERIZATION($,$,
#1220,#1410);
...
#1670 = LINE($,#1130,#1680);
#1680 = VECTOR($,#1690,2.4);
```

```
#1690 = DIRECTION($,(0.,-2.4,0.));
#1700                                              =
EDGE_CURVE($,#1540,#1550,#1580,.T.);
...
```

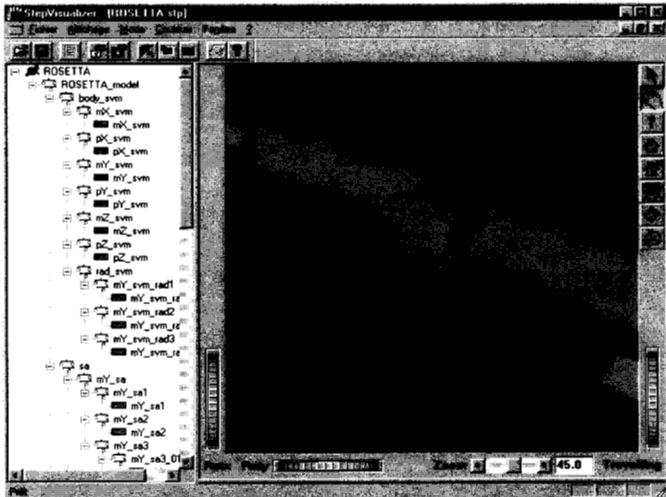The STEP-TAS file is checked with Baghera View :

Figure 17 : Export checking with Baghera View

The STEP-TAS file is then converted into a TRASYS file with a converter which has been developed in a few weeks by a JPL engineer using the STEP-TAS High Level library :

```
HEADER OPTIONS DATA
TITLE    ROSETTA
         MODEL=ROSETT
C
...
BCS    mY_svm_rad1_1
S        SURFN = 331,
         TYPE = RECT
         NNX=1, NNY=1
         ALPHA=0.180,            EMISS=0.800,
TRANS=0.000, SPRI=1.000, SPRS=1.000
         ACTIVE = TOP
         P1 =    0.000,    0.000,    0.000
         P2 =    0.650,    0.000,    0.000
         P3 =    0.000,    1.050,    0.000
         COM = Surf SL=,SI=mY_svm_rad1
         COM = FI=mY_svm_rad1_face1
         COM = PI=Thermo-optical properties
ros_cmx_gap_10y
...
```

In the opposite way, we started from a TSS model of Mars Pathfinder :
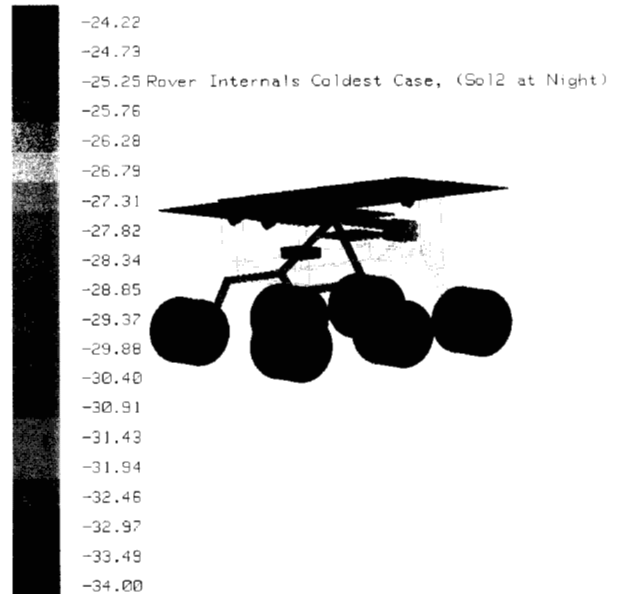

Figure 18 : TSS input

The TSS file is converted into STEP-TAS with some calls to the STEP-TAS High Level Library and after having been checked with Baghera View, the STEP-TAS file is loaded into ESARAD :
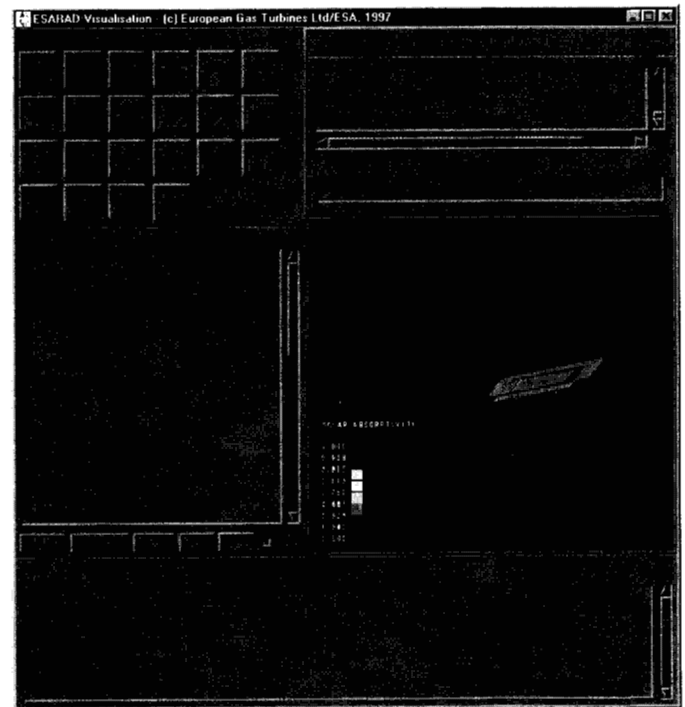

Figure 19 : TSS file imported into ESARAD

CONCLUSION

Like most industries, the space industry can realize substantial benefits from using STEP (ISO-10303) for exchanging technical data between partners. Geometrical data exchange using the STEP AP203 application protocol are now available and accurate between most CAD systems (CATIA, Pro*Engineer, Autocad...).

Based on the success of this protocol, some new ones are under development which can fit the needs of other space engineering disciplines, like structural (AP209) or thermal analysis (STEP-TAS), electromechanical definition (AP212) or product configuration (AP232).

In the thermal analysis domain, the two European software programs, ESARAD from ESA and THERMICA from Matra Marconi, now have a STEP-TAS interface, although STEP-TAS has not yet completed the process of becoming an international standard. The feasibility study with NASA/JPL has proven that interfacing NASA thermal tools to this protocol requires only a moderate amount of work.

Step opens the door to very effective cooperation between space industry partners and now is the time to speed up its implementation.

ACKNOWLEDGMENTS

CONTACT

Eric Lebègue is the technical manager of Espri Concept, a French services software company. He is a member of the French delegation to ISO/TC 184 / SC4 committee for STEP project development and also a member of the ECSS committee for product data standardization inside the European space industry.
Eric Lebègue has been charged by ESA, in 1998, to lead the project STEP-TAS&NRF.
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For the STEP application protocols, see the "THE STEP APPLICATION PROTOCOLS NETWORK FOR THE SPACE INDUSTRY" paragraph.

DEFINITIONS, ACRONYMS, ABBREVIATIONS

AAM:
Application Activity Model

AIM:
Application Interpreted Model

API:
Application Programming Interface

ARM:
Application Reference Model

CAD:
Computer Aided Design

ECSS:
European Co-operation for Space Standardization.

ISO:
International Standard Organization

NRF:
Network based Results Format

OMT:
Object Modeling Technology

SDAI:
Standard Data Access Interface

STEP:
Standard for the Exchange of Product model data

TAS:
Thermal Application for Space

UML:
Unified Method Language